most used approach is to create heavily doped regions under the metal, *p*-type for hole extraction and *n*-type for electron extraction. Majority carriers in this region can flow through the contact with low voltage loss. The transport of minority carriers is described by a surface recombination velocity (SRV), S. Although the SRV is high, limited only by thermal diffusion so that $S \cong 10^6$ cm·s^{-1} [15], the concentration of minority carriers, for a given *pn* product, is suppressed by the high doping and the flow is reduced.

As will be seen later on, the contact for the minority carriers is usually placed at the front (illuminated) face of the substrate, and the corresponding heavily doped layer is usually called *emitter*. The doped region under the majority carrier contact at the back is called a *Back Surface Field* (BSF).

Recombination at these heavily doped regions is described by the saturation current density J_0 that includes volume and true contact recombination. Their thickness w should be much higher than the minority-carrier diffusion length L so that few excess carriers reach the contact, and the doping level must be very high to decrease contact resistance and the minority-carrier concentration, although heavy doping effects may limit the doping level advisable for such regions. The recombination activity of BSF layers is often described in terms of an effective SRV instead of the saturation current density.

Typical 10^{-13} to 10^{-12} A·cm^{-2}J_0 values are achieved [16, 17]. Diffused phosphorus is used for *n*-contacts. Aluminum alloying has the advantages over boron for *p*-contacts that very thick p$^+$ layers can be formed in a short time at moderate temperatures and that gettering action is achieved [18]. As a shortcoming, the p$^+$ layer is nonhomogeneous and can even be locally absent; the obtained J_0 is larger than expected for a uniform layer. In comparison to aluminum, boron offers higher doping levels because of a larger solubility [19] and transparency to light so that it can also be used at illuminated surfaces.

Other structures have been tested to obtain selective contacts: metal-insulator-semiconductor (MIS) contacts [20], polysilicon contacts [21] and heterojunction to a-Si or other wide band gap material [22].

7.2.2.2 Noncontacted surfaces

Because of the severe alteration of the bonding of Si atoms, a large number of band gap states exist at a bare Si surface which, acting as SRH recombination centers, make the SRV very large, around 10^5 cm·s^{-1} [23, 24]. In order to reduce surface recombination, two main approaches are followed [25].

In the first one, the density of electron surface states in the gap is decreased. This is accomplished by depositing or growing a layer of an appropriate material that partially restores the bonding environment of surface Si atoms. This material must be an insulator.

Thermal SiO_x is grown in an oxygen-rich atmosphere at the expense of substrate Si atoms at high temperatures around 1000°C. SiN_x is deposited by plasma-enhanced chemical vapor deposition (PECVD) [26] at low temperatures between 300 and 400°C range. The quality of both techniques is very sensitive to subsequent treatments, with hydrogen playing a major role in obtaining low SRV values below 100 cm·s^{-1}.

As a general rule, S increases with the doping of the substrate [23, 24]. It also depends on the injection level and doping type, because the interfaces contain positive